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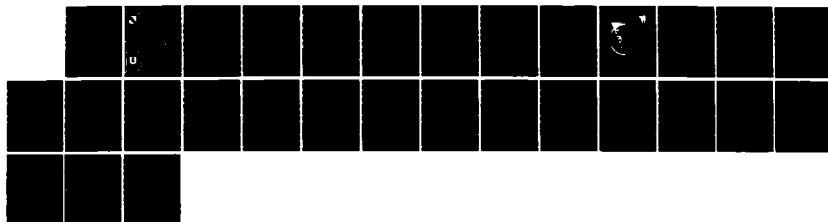
EXPERT SYSTEM ADVICE: HOW SHOULD IT BE GIVEN?(U) FRANK
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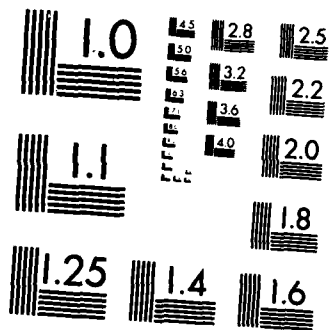
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FRANK J. SEILER RESEARCH LABORATORY

FJSRL-TR-86-0007

AUGUST 1986

EXPERT SYSTEM ADVICE;

HOW SHOULD IT BE GIVEN?

FINAL REPORT

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OCT 27 1986
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Capt Anthony Aretz, Maj Al Guardino, Lt Thomas Porterfield,
and Lt Jim McClain

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AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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This technical report has been reviewed and is approved for publication.


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SUMMARY

The objective of this research was to investigate different alternatives for pilot-computer interaction with a simulated expert system. Three methods of advice presentation were investigated -- automatic, subject requested, and a combination of the two. Also, three experience levels of the subjects were examined -- novice, intermediate, and expert. The dependent variables were total score for successful missions completed during the experimental session and average time to complete a successful mission. The analysis of the data revealed that the automatic condition was the best overall method for advice presentation ($p < .1$) and the experience level of the subjects was not a significant factor.

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INTRODUCTION

Although a fighter mission is rather complex, the pilot's duties can be divided into five broad categories: piloting the aircraft; navigation to and from the primary target; weapon delivery; threat avoidance and elimination; and management of aircraft systems (e.g., fuel). It is apparent that such a mission requires the pilot to process a great deal of information. In an effort to aid the pilot, the Air Force has already initiated research into a program called "The Pilot's Associate". The Pilot's Associate is being funded by the Defense Advance Research Project's Agency (DARPA) and its goal is to build a prototype expert system, based on artificial intelligence, to aid a pilot in the performance of a mission. One critical question yet unanswered by the program, however, is how the interaction between the pilot and the expert system can be efficiently accomplished.

Although expert systems already exist for a variety of applications, from providing medical pulmonary diagnoses to analyzing geographic data for drilling oil wells (Cohen and Figenbaum, 1983), trying to apply expert systems to fighter cockpits is a little more difficult. Unlike these other situations, each fighter mission is a dynamic scenario often deviating from what was expected or briefed; consequently there is a greater need for accurate real-time information.

For a pilot to use such an expert system effectively, the interaction with the system should be designed in the most efficient manner. This paper presents initial results from a research effort that investigated different alternatives for advice presentation. The three alternatives investigated were: (1) Automatic - the mission was tracked and advice was automatically provided to enhance performance; (2) Request - the mission was tracked and advice was provided only when queried by the pilot; and (3) Both - a combination of the previous two methods. Voice synthesis was chosen as the mode for giving the advice based on the assumption that future cockpits will use a voice input/output system as one method to communicate with the computer.

Besides the presentation style, a second factor to consider in designing this expert system is the varying levels of experience of the pilots who will use it. You would expect that a novice pilot would be helped more by an expert system. As a pilot gains experience, however, their internal model of the mission broadens and the same advice may not be as helpful or may even hinder performance if the advice conflicts with their model. Morris, Rouse, and Frey (1984) hypothesized that subjects would rely more heavily on a decision aiding system when their perceived performance is poor (i.e., inexperienced subjects) compared to when their perceived performance is good.

METHOD

Subjects

Twenty-nine male USAF Academy cadets from all four classes served as volunteer subjects in this experiment. Subjects were initially screened so that only those with prior experience in playing F-15 Strike Eagle were used. However, ten cadets who had not played this game were used as novices to balance the sample sizes for the 'experience' variable. Also, the data for four other subjects was eliminated from the analysis because they failed to score any points during at least one of their sessions.

Apparatus

Simulation. The fighter mission was simulated using the commercially available F-15 Strike Eagle video game developed by MicroProse Software and was played on a Kaypro 16 computer with a color monitor. This video game simulates several air-to-ground mission scenarios with varying levels of difficulty. The game also has a variety of threats (i.e., enemy aircraft and heat seeking and radar guided missiles) to deal with while flying the missions. There are a total of seven missions and four levels of difficulty -- arcade, rookie, pilot and ace. In addition, each successive mission is more demanding at each level of difficulty.

To present the necessary information for the missions, the game uses four primary displays: a Head Up Display (HUD), tactical situation display, radar electronic warfare display,

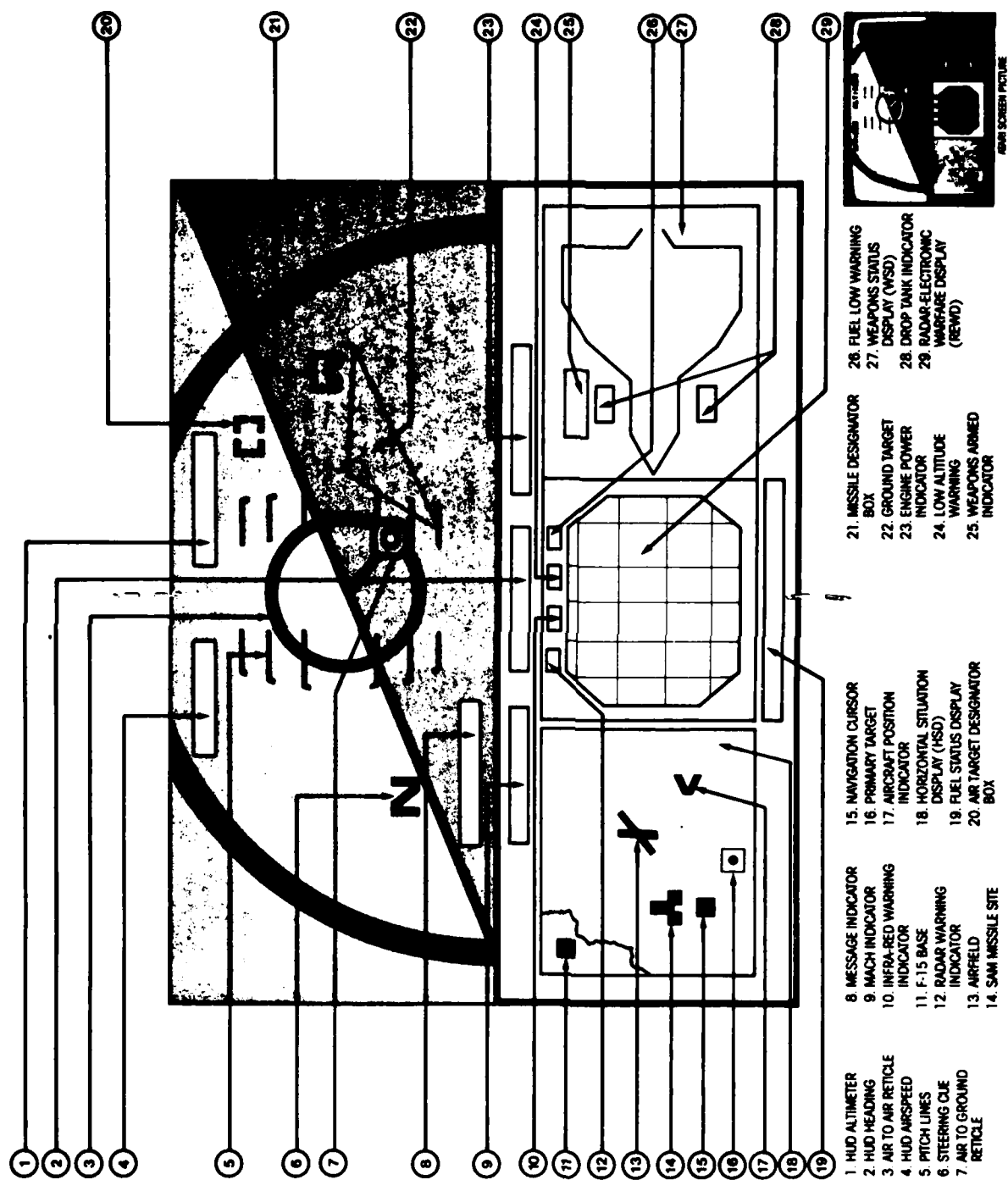


Figure 1. F-15 Strike Eagle Cockpit Layout.

and a pictorial stores display (Figure 1). The offensive and defensive weapons include Electronic Counter Measures (ECM), flares, dumb bombs, and short and medium range missiles. Lastly, systems information is provided for fuel, heading, airspeed, and altitude. Therefore, with the game's very solid aerodynamic model and demands placed on the human information processing resources, this game realistically approximates the fighter cockpit environment quite well.

To further enhance the game's realism, it was played in a modified Air Force T-38 simulator that contained three color Cathode Ray Tubes (CRTs). The video game was presented on the CRT located in the HUD position. The subjects controlled the game through a joystick and computer keyboard that had also been mounted in the cockpit. In addition, four lighted push button switches were mounted on the forward position of the left side panel for the subjects to request advice.

Expert system. The expert system advice was simulated by an experimenter using a Texas Instruments Business Pro computer equipped with a TI Speech II board allowing text-to-speech voice synthesis. The expert system advice was stored in the computer in a series of text phrases and was selected by the experimenter from a menu. An example of one of the phrases is: "Warning! Heat seeking missile, deploy flare." All together there were 26 different advice prompts that could be given to the subject. (See Appendix A for a

complete listing of the phrases used.) The expert system was then simulated by having the experimenter track the mission on a separate CRT and select the appropriate advice, depending on the experimental condition, to be presented to the subject. The subjects were presented an average of 80 advice prompts in the automatic condition during an experimental session. Communications among the expert system, subject, and experimenter occurred over an intercom system through a microphone and headset.

Experimental Design

The experimental paradigm used for this study was a four by three mixed factor, repeated measures design. The within-subjects design involved the expert system presentation style and had four levels: automatic, request, both, and a control where no advice was given. To eliminate possible learning effects from confounding the data, the order of presentation of the treatments to each subject was counterbalanced using a balanced latin square so that each condition was preceded and followed equally often by each of the other conditions.

A between subjects design was used for the experience level of the subject and had three levels: novice, intermediate, and expert. Subjects were grouped by experience level based on the performance of a pre-test with the game. (See the Pre-Test section of this report for further details.) All subjects completed at least two missions successfully prior to the experiment.

Dependent Variables

The dependent variables were the total score for the successfully completed missions during each experimental session and the average time to complete these missions. For a subject to successfully complete a mission, they were required to destroy the primary target and safely return to home base.

Procedures

Pre-test. Prior to participating in the experiment, all subjects were pre-tested on the video game. Each subject flew the two easiest missions at each level of difficulty, starting at the rookie level, until they completed the two missions at the ace level or until they had flown a total of two unsuccessful missions. Subjects were then categorized by experience based on the highest level of difficulty in which two missions were flown successfully. Beginners completed two missions successfully at the rookie level, intermediates completed two at the pilot level, and experts completed at least one at the ace level. The pre-test was administered approximately one month prior to participation in the experiment for most subjects. The subjects were also told not to play the video game again prior to their participation

in the data collection portion of the study and all had complied.

Experimental sessions. Subjects flew the simulation for forty minutes under each condition on four different days. Each subject flew each condition at approximately the same hour of the day and had at least one rest day between experimental sessions.

Subject briefing. Prior to the session, the subjects were told which condition they would see that day. The experimenter would then use the computer and text-to-speech synthesis to play the experimental instructions. (See Appendix B for an example of the instructions.) The subjects were then reminded of the condition they would be flying under and that their mission objective was to fly directly to their primary target, attack the target, and return to home base as quickly as possible; they were only to attack threats that endangered the success of the mission.

For the request and both conditions, the subjects were also briefed on the operation of the four switches in the cockpit. There was one switch each to request advice on: 1) navigation, 2) offensive and defensive weapons, 3) aircraft systems, and 4) a switch labeled with a question mark to be used by the subject when they did not know what specific type of advice to request.

Data collection. Each subject started each session flying mission number four at the rookie level. If the mission was flown successfully the subject then flew mission number six at the same level. However, if the mission was not successful (i.e., crashed, shot down, or failed to destroy the primary target), the subject repeated the same mission until it was completed successfully. If the subject completed these two missions successfully they were then advanced to the pilot level of difficulty and again flew missions four and six. If the missions were successful again, the subject advanced to the ace level. Subjects advanced in this manner as far as they could during the forty minute session. No subject was able to complete the total of six possible missions during the session. Upon completion of each successful mission the total score and time to complete the mission were recorded. Following each session the subjects were administered a questionnaire to collect subjective data for that condition and a final questionnaire was given following all four treatments. (See Appendix C for examples of the questionnaires.)

RESULTS

The data were analyzed using the MANOVA for repeated measures procedure in the SPSS/PC+ statistical package for microcomputers (Norusis, 1986). The results of this analysis revealed only one significant effect which was the main effect of the advice presentation condition ($F=1.81$, $p=.1$;

Table 1). In addition the univariate results revealed that only the total score contributed significantly to this result ($F=2.63$, $p=.056$; Table 2). Figure 2 shows a plot of the mean total score for each of the experimental conditions.

Table 1
Pillais Summary Table

Source	Value	Approx. F	Hypoth. df	Error df	p
(Between)					
Experience	.38360	3.08514	4.0	52.0	.024
(Within)					
Condition	.13023	1.81089	6.0	156.0	.100
Condition X Experience	.13909	.97168	12.0	156.0	.478

Table 2
Univariate Test Results

Variable	df	SS	MS	F	p
Score	3	33194711.0	11064903.7	2.62812	.056
Error	78	328395318.0	4210196.4		
Avg. Time	3	9.61820	3.20607	1.02602	.386
Error	78	243.73165	3.12476		

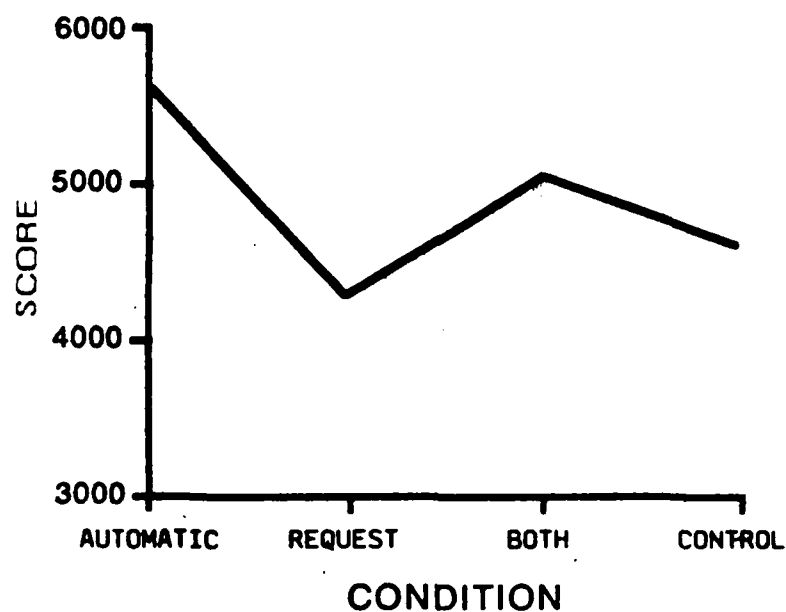


Figure 2. Mean Score by Condition.

A Duncan post-hoc test was then used to compare the means, and the results showed the automatic condition was significantly different from the request and control conditions ($p < .1$) but not the both condition (Table 3).

Table 3

Results of the Duncan Test For Differences
Between Means

	Request	Both	Control
Automatic	1310*	541	991*
Request		769	319
Both			450

* $p < .1$

The number of requests for advice made by each subject in the request condition was also analyzed by experience level but no significant effect was found ($F < 1$). All subjects averaged 24.47 requests per session.

Questionnaire Results

The results of the questionnaire were analyzed using a Chi-Square goodness of fit test for a uniform distribution (See Appendix C). Several interesting findings emerged from this analysis. First, 26 subjects agreed the advice was essential or helped quite a bit in the performance of the missions ($\chi^2 = 50.2$, $p < .005/df = 5$). Second, 17 subjects ranked the automatic condition as the best overall method for advice presentation ($\chi^2 = 9.44$, $p < .01/df = 2$). Finally, all the subjects felt that threat management was the area where the advice was most helpful ($\chi^2 = 88.26$, $p < .005/df = 3$).

DISCUSSION

Based on the analysis above, several points can be made. First, from both the objective and subjective data it is apparent that the presentation of advice did improve mission performance and that the automatic condition was the best overall method for advice presentation. In fact, one subject noted in his final comments "I was really surprised at how much worse my performance was with no advice as compared to my performance under the advice condition. I think the voice talking gave you a certain level of confidence as well as pertinent information." In today's complex fighter cockpit

environment, the pilot does not have the attentional resources available to monitor every aspect of the mission. By providing the automatic advice to the subject, the subject was warned of critical events (e.g., threat warnings) that were important to the success of the mission. Therefore, information processing resources only had to be diverted to other tasks when critical developments occurred that mandated attention.

Second, the fact that the automatic condition was better than the request condition indicated that the additional resources required to request advice were great enough to decrease overall mission performance. To request advice in this experiment, the subject had to divert attention away from the primary task of flying the mission and press one of the switches in the cockpit. It would appear that in a situation where the pilot is already extremely taxed, any additional resources allocated for other tasks can cause performance to deteriorate. Therefore, an expert system should keep additional requirements for information processing resources to a minimum if possible. As an example, an improvement over the present configuration might have included a voice activated system.

Third, the results failed to show a significant effect for the experience level of the subject. It was expected the advice would be less helpful for the more experienced subjects since they had already built an internal model of

how to fly the missions and the advice might have interrupted their thoughts or even conflicted with their plans. This was not the case and it appears that even expert subjects can benefit from expert system advice. This again is probably because information processing requirements were high even for the experts and the expert system was able to alert them to significant events they may not have detected.

Finally, no differences were found among the experience levels of the subjects as to how much advice was requested in the request condition. As was said earlier, Morris, et. al., (1984) hypothesized that the more a subject perceived their performance to be poor, the more they would rely on a computer decision aid. In this study, it was expected that novice subjects would perceive their performance as sub-standard and rely more heavily on the advice by making more requests than the experts. This did not happen and it seems that the novice and expert subjects perceived their performance on the same level and both relied on the advice equally. However, one subject did state in his final comments that "As I got better the computer advice became less helpful."

One final point that needs to be made is that with an expert system that is able to monitor the progress of a mission and provide advice to the pilot, it might be used to further reduce the pilot's workload and improve mission performance if it could actually perform some of the mis-

sion's tasks for the pilot. This is the logical next step for expert systems and future research is being planned to investigate issues dealing with how the pilot would interact with such a system.

CONCLUSIONS

It is obvious that for an on-board expert system to efficiently contribute to the performance of a fighter mission, the pilot-computer interface must be understood and specified. This research supports the concepts that expert system advice should be presented automatically and that additional information processing requirements due to the expert system should be kept to a minimum.

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- NORUSIS, M.J. (1986). SPSS/PC+ Advanced Statistics. Chicago, IL: SPSS Inc.

APPENDIX A
Advice Prompts Used

1. WARNING, RADAR GUIDED MISSILE, ACTIVATE ECM.
2. WARNING, HEAT SEEKING MISSILE, DEPLOY FLARE.
3. WARNING, PULL UP, ALTITUDE DANGEROUSLY LOW.
4. CAUTION, ALTITUDE TOO HIGH FOR BOMB DROP, DESCEND TO 2000 FEET.
5. WARNING, AIRSPEED DANGEROUSLY LOW, INCREASE THROTTLE.
6. WARNING, AIRSPEED DANGEROUSLY HIGH, DECREASE THROTTLE.
7. WARNING, ENEMY AIRCRAFT, FIRE A SHORT RANGE MISSILE.
8. WARNING, ENEMY AIRCRAFT, AIM AT THE AIRCRAFT AND FIRE A MEDIUM RANGE MISSILE.
9. WARNING, LOW FUEL, RETURN TO BASE.
10. ADVISORY, FOR EFFICIENT FUEL USAGE, REDUCE THROTTLE TO 95 PERCENT.
11. ADVISORY, YOU CAN JETTISON YOUR DROP TANKS.
12. ADVISORY, FOR NAVIGATION TO THE TARGET, DESIGNATE IT WITH THE NAVIGATION CURSOR.
13. ADVISORY, FOR NAVIGATION TO HOME BASE, DESIGNATE IT WITH THE NAVIGATION CURSOR.
14. ADVISORY, APPROACHING PRIMARY TARGET, ARM A BOMB.
15. ADVISORY, FOR EFFICIENT FUEL USAGE, DISENGAGE AFTER-BURNER.
16. ADVISORY, TO INCREASE AIRSPEED, ENGAGE AFTERBURNER.
17. ADVISORY, TO LOOSE ALTITUDE FAST, REDUCE POWER TO 55 PERCENT, AND ACTIVATE SPEED BRAKES.
18. ADVISORY, YOU HAVE OVERFLOWN THE TARGET, FLY STRAIGHT FOR A FEW SECONDS, DO A LOOP, AND GET BACK ON COURSE.
19. CAUTION, YOU ARE OUT OF MISSILES, TO DEFEAT AIR THREATS YOU MUST OUT MANEUVER THEM OR USE GUNS.

20. YOU ARE OUT OF FLARES, TO DEFEAT HEAT SEEKING MISSILES YOU MUST OUT MANEUVER THEM.
21. CAUTION, YOU ARE OUT OF ECM, TO DEFEAT RADAR GUIDED MISSILES YOU MUST OUT MANEUVER THEM.
22. ADVISORY, FOR AN EASIER BOMB RELEASE, DECREASE THROTTLE TO 55 PERCENT.
23. ADVISORY, YOU ARE OFF COURSE.
24. CAUTION, ALTITUDE TOO HIGH FOR RETURN TO BASE, DECREASE TO 3000 FEET.
25. WARNING, YOU ARE RUNNING OUT OF FUEL, CLIMB AS HIGH AS YOU CAN, AND DO A POWER-OFF GLIDE INTO HOME BASE.
26. CAUTION, YOU SHOULD DEACTIVATE YOUR SPEED BRAKES BY PRESSING A THROTTLE SETTING.

APPENDIX B

Instructions to the Subjects

HELLO. I AM YOUR ON-BOARD INTELLIGENT COMPUTER. MY PURPOSE, IS TO HELP YOU FLY YOUR MISSION SUCCESSFULLY. DURING YOUR MISSIONS, I WILL PROVIDE YOU WITH ADVICE, AUTOMATICALLY, ON WAYS TO IMPROVE MISSION PERFORMANCE. IF YOU LISTEN TO MY ADVICE, YOU WILL BE MORE LIKELY TO COMPLETE YOUR MISSION SUCCESSFULLY. HOWEVER, IF YOU DO NOT LIKE THE ADVICE I GIVE YOU, YOU MAY CHOOSE TO IGNORE IT. YOUR MISSION TODAY, WILL BE TO ATTACK THE PRIMARY TARGET AS INDICATED ON THE TACTICAL SITUATION DISPLAY. SOMETIMES, YOU MAY HAVE TO RETURN TO BASE, TO REFUEL, BEFORE COMPLETING YOUR MISSION. OUR ATTACK ORDERS ARE TO FLY DIRECTLY TO THE TARGET, ATTACK THE TARGET, AND RETURN DIRECTLY TO HOME BASE. ONLY ATTACK THE THREATS THAT ENDANGER THE SUCCESS OF THE MISSION. IF YOU HAVE ANY QUESTIONS, ASK THE EXPERIMENTER AT THIS TIME.

APPENDIX C

POST FLIGHT QUESTIONNAIRE
AUTOMATIC ADVICE CONDITION

SUBJECT NO.: _____

Circle the appropriate answer:

1. Did you find the computer advice helpful in the performance of the mission?

$$X^2=20.8; p<.0001/df=4$$

Not at All Very Little Somewhat Quite a Bit Essential

0 4 9 15 4

2. How easy was it to understand the advice that was given to you?

$$X^2=41.8; p<.0001/df=4$$

Very Difficult Difficult Somewhat Difficult Easy Very Easy

0 0 2 18 12

3. Was the timing of the computer advice appropriate?

$$X^2=35.2; p<.0001/df=4$$

Unacceptable Bad Satisfactory Good Optimum

0 3 15 14 0

4. Did you find the computer advice to be a distraction?

$$X^2=58.5; p<.0001/df=4$$

Not as All Very Little Somewhat Quite a Bit Always

4 24 3 1 0

5. Rank order the following as to which category of advice was most helpful (1=most helpful; 4=least helpful;

- 1 Threat Management (ECM, Flares, and Missiles)
- 4 Navigation (To the target and home base)
- 2 Weapons Management (Bombing the primary target)
- 3 Systems Management (Fuel, Airspeed, Altitude, ect.)

6. What was the easiest and most difficult aspects of the missions for you, and did the advice help in these aspects?

Easiest: Navigation (92%)

Most Difficult: Threat Management (96%)

**POST FLIGHT QUESTIONNAIRE
REQUEST ADVICE CONDITION**

SUBJECT NO.: _____

Circle the appropriate answer:

1. Did you find the computer advice helpful in the performance of the mission? $X^2=10.5$; $p=.033/df=4$

Not at All	Very Little	Somewhat	Quite a Bit	Essential
3	6	13	7	3

2. How easy was it to understand the advice that was given to you? $X^2=43.7$; $p<.0001/df=4$

Very Difficult	Difficult	Somewhat Difficult	Easy	Very Easy
0	0	1	19	10

3. When requested, Was the timing of the computer advice appropriate? $X^2=26.1$; $p<.0001/df=4$

Unacceptable	Bad	Satisfactory	Good	Optimum
0	5	15	11	1

4. How often did you use the computer advice? $X^2=14.5$; $p=.006/df=4$

Not as All	Very Little	Somewhat	Quite a Bit	Always
2	8	5	14	3

5. Rank order the following as to which category of advice was most helpful (1=most helpful; 4=least helpful; 0=not used):

<u>1</u>	Threat Management (ECM, Flares, and Missiles)
<u>3</u>	Navigation (To the target and home base)
<u>2</u>	Weapons Management (Bombing the primary target)
<u>4</u>	Systems Management (Fuel, Airspeed, Altitude, ect.)

6. What was the easiest and most difficult aspects of the missions for you, and did the advice help in these aspects?

Easiest: Navigation (97%)

Most Difficult: Threat Management(100%)

**POST FLIGHT QUESTIONNAIRE
AUTOMATIC AND REQUEST ADVICE CONDITION**

SUBJECT NO.: _____

Circle the appropriate answer:

1. Did you find the computer advice helpful in the performance of the mission?

$$X^2=34.6; p<.0001/df=4$$

Not at All	Very Little	Somewhat	Quite a Bit	Essential
0	0	11	17	4

2. How easy was it to understand the advice that was given to you?

$$X^2=35.8; p<.0001/df=4$$

Very Difficult	Difficult	Somewhat Difficult	Easy	Very Easy
0	0	3	16	13

3. Was the timing of the automatic computer advice appropriate?

$$X^2=24.6; p<.0001/df=4$$

Unacceptable	Bad	Satisfactory	Good	Optimum
0	6	15	10	1

4. Did you find the automatic computer advice to be a distraction?

$$X^2=39.2; p<.0001/df=4$$

Not as All	Very Little	Somewhat	Quite a Bit	Always
4	22	5	1	0

5. How often did you request advice?

$$X^2=5.8; p=.214/df=4$$

Not at All	Very Little	Some	Quite a Bit	Always
3	10	9	6	4

6. Did you find the automatic or requested advice to be most helpful?

$$X^2=14.2; p<.0001/df=1$$

Automatic	Requested
26	5

7. Rank order the following as to which category of advice was most helpful (1=most helpful; 4=least helpful)

- | | |
|----------|---|
| <u>1</u> | Threat Management (ECM, Flares, and Missiles) |
| <u>4</u> | Navigation (To the target and home base) |
| <u>2</u> | Weapons Management (Bombing the primary target) |
| <u>3</u> | Systems Management (Fuel, Airspeed, Altitude, ect.) |

8. What was the easiest and most difficult aspects of the missions for you, and did the automatic or requested advice help in these aspects?

Easiest: Navigation (90%)

Most Difficult: Threat Management (98%)

FINAL QUESTIONNAIRE

SUBJECT NO.: _____

Circle the appropriate answer:

1. Did you find the computer advice helpful in the performance of the missions?

$$X^2=50.2; p<.0001/df=4$$

Not at All Very Little Somewhat Quite a Bit Essential

0 1 5 22 4

2. How easy₂ was it to understand the advice that was given to you?

$$X^2=52.7; p<.0001/df=4$$

Very Difficult Difficult Somewhat Difficult Easy Very Easy

0 0 1 21 10

3. Rank order the following as to which category of advice was most helpful (1=most helpful; 4=least helpful;

- 1 Threat Management (ECM, Flares, and Missiles)
- 4 Navigation (To the target and home base)
- 2 Weapons Management (Bombing the primary target)
- 3 Systems Management (Fuel, Airspeed, Altitude, ect.)

4. Rank order the methods for advice presentation as to which method of presentation was most helpful (1=most helpful; 3=least helpful;

- 1 Automatic
- 3 Request Only
- 2 Both Automatic and Request

5. What was the easiest and most difficult aspects of the missions for you, and did the autotmatic or requested advice help in these aspects?

Easiest: Navigation (92%)

Most Difficult: Threat Management (94%)

END

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